学位論文内容の要旨

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学 位 論 文 題 目

Estimates of Japanese sandeel (*Ammodytes personatus*) distribution and biomass in the northern coast of Hokkaido, Japan, using a quantitative echosounder
（計量魚群探知機を用いた北海道北部沿岸域におけるイカナゴ (*Ammodytes personatus*)の分布と生物量の推定）

1.Introduction

Japanese sandeel (*Ammodytes personatus*, sandeel herein) plays an important role in marine ecosystems, not only as a food source for many marine organisms but also as a target fish of Japanese fisheries. The fishing season for the adult sandeel fisheries in the northern coast of Hokkaido occurs during summer (June-September) of every year. However, the status of sandeel stock just before the fishing season and the relationship between oceanographic changes in the fishing grounds are not well understood. To ensure efficient fisheries management policies in the future, fishery-independent methods that support the sandeel distribution and abundance estimates are sought. In this study, acoustics as a scientific quantitative method was employed to fulfill the shortcomings in the previous attempts to estimate the sandeel distribution and biomass and in relation to their environmental changes in the northern coast of Hokkaido. Acoustic method is recognized as reliable for fish stock monitoring. It can provide *in-situ* with real time fish abundance and it is possible to obtain both presence and absence of fish. In addition, it could be non invasive, high-resolution and also it can covers large areas quickly. From an acoustics point of view, sandeel is a challenging fish, mainly because it has a weak acoustic target and peculiar behavioral traits. They form compact schools in the water column during the day, and subsequently descend to the bottom substrate at dusk. Therefore, acoustic survey is suitable when conducted in daytime to estimate quantitatively their biomass and distribution.

The objective of this study was to estimate sandeel distribution and biomass in the northern coast of Hokkaido, Japan, using a quantitative echosounder. Furthermore, it was to get a better understanding of the effects of oceanographic conditions on sandeel distribution and biomass.

2. Methods and instruments

Swimming angles of adult sandeel were collected from free-swimming sandeel at the Wakkanai Fisheries Research Institute, Hokkaido Research Organization, Japan. The experiment was conducted in a rectangular tank (2.05 m × 2.0 m × 1.2 m). The swimming angle of fish was recorded using a digital HD video camera recorder. A video camera was set up in front of the experimental tank. Furthermore, the theoretical model was applied to estimate TS variation as a function of fish swimming angle. The theoretical TS were estimated using distorted-wave Born approximation (DWBA) model at two frequencies responses (38 and 120 kHz) for dorsal aspect. Laboratory measurements were carried out to obtain the measured TS at the National Research Institute of Fisheries Engineering, Fisheries Research Agency, Ibaraki, Japan. The experiments were conducted in an indoor tank (10 m × 15 m × 10 m) on dead fish. An echosounder unit, split beam transducer set on the bottom of the tank operating at 38 kHz was employed to measure the TS of individual sandeel.

To estimate sandeel distribution and biomass, field surveys were conducted. The study area was located off Sarufutsu, northern coast of Hokkaido, Japan. A random design of transect lines acoustic and oceanographic sampling using a CTD were conducted annually during the summer of June 2010 and 2011 and July 2012, respectively. In July 2009, only acoustic data was available. These were the months just before the main fishing season for adult sandeel began in the study area. An otter trawling (local commercial fisheries) was used to identify sandeel size compositions directly for the recording of acoustic back scatterings during the acoustic surveys.

Acoustic data were analyzed using echoview version 4.90 software (Myriax Software Pty, Ltd). Volume backscattering strength (SV) difference method was applied to identify sandeel schools in the acoustic data. Further, it was converted to biomass density (ind.m^{-2}). Generalized additive models (GAMs) and Generalized linear models (GLMs) were applied to detect the effects of oceanographic factors on the sandeel distribution in the presence/absence and in presence scenarios. The temperature and salinity structures of each sandeel school in the water column were interpolated by Geographical Information System (GIS) software (ESRI, Arc.GIS 10.0). The sandeel distribution and biomass density overlain on oceanographic conditions such as temperature and salinity with depth ranges in the different year were visualized using Ocean Data View (ODV4).

3. Results and discussion

Twenty live fishes ranging from approximately 21.0 to 28.7 cm in standard length (*SL*, cm) were used to measure the swimming angle of sandeel. To calculate the swimming angle, 1,197 images collected from approximately 11 hours of video records were used. Bimodal distribution of sandeel swimming angle was found. It may have occurred due to the small sample size in measurements (n=95). The mean and the standard deviation of swimming angles were 20.38 ± 18.5^{o}, respectively. Sandeel are generally negatively buoyant (swimbladderless fish). Consequently, they must swim with some positive body tilt to maintain the altitude and often swim with a slight *head-up* posture.

The varied TS in relation to the changes in the swimming angles showed peaks at around 0^{o} at both frequencies. The TS values at both frequencies of smaller fish length were consistent near the main lobe. However, the values of TS at 38 kHz were higher than those at 120 kHz for larger fish length. In most cases (n =72), the averaged TS in adult sandeel at 38 kHz was higher than that at 120 kHz. The best fit regression lines for 38 and 120 kHz were $TS_{38kHz} = 8.2\log_{10}SL - 74.2$ and $TS_{120kHz} = 20.9\log_{10}SL - 92.6$, respectively. It was found that the swimming angles had a large effect on TS variations. These results strengthened the previous study that the TS values for a swimbladderless fish is dependent on swimming angle, and that the variations with the changes in the angle are large. The results of TS-length relationship obtained for individual sandeel will be useful in the analysis of the averaged backscattering cross-section of sandeel schools. Correlation coefficients of TS value results are calculated to evaluate the goodness of fit between the theoretical and experimental TS. It was noted that there was consistency for both TS experiments.

The TS difference value of individual sandeel (n=72) was estimated by DWBA model at 38 and 120 kHz in the range of –5 to +3 dB, which was applied to identify sandeel school. It was found that sandeel schools were distributed mainly near the coastal waters, and were mostly concentrated in the western part of the study area. It was noted that the biomass densities of the schools ranged from 1–25 ind. m^{-2}. Sandeel biomasses varied each year. The higher fish abundance was found in 2012 (119.5 tons) and lower abundance occurred in 2011 (5.2 tons)

Generalized additive models (GAMs) as a nonlinear model were more robustly used than GLMs, were succeeded to identify the effects of oceanographic factors on the sandeel distribution in presence/absence and in presence (revealed by the shape of the smoothes among predictor factors). Sandeel schools tended to be distributed in the specific range of oceanographic factors. They prefer warmer (10.5–13.8^{o}C), saline (33.6–33.7 psu) and shallow (less than 45 m) waters.

4. Conclusions and further considerations

This study had explored and examined several methods which could be improved in the acoustic estimates of Japanese sandeel distribution and biomass in the northern coast of Hokkaido. Firstly, the study revealed that the sandeel intended to display a positive angle as indicated in the mean and standard deviation values. Secondly, it was found that the TS difference value of individual sandeel estimated by DWBA model at 38 and 120 kHz in the range of –5 to +3 dB. This information is useful in the identification of adult sandeel school in the field using acoustic methods. The study expanded the results and revealed natural fluctuations of sandeel stocks in the northern coast of Hokkaido. This study noted that sandeels migrating in the northern coast of Hokkaido could have followed the interruption of SWC water during summer months which occupied the warmer and saline waters of the area. These suitable conditions may represent the optimal habitat for the sandeel especially in the study area in summer.

To avoid a depletion of the Japanese sandeel stock in the northern coast of Hokkaido, the accuracy of the sandeel stock status in the field is essential. To improve the understanding of this situation, stakeholders such as scientists together with stakeholders must seek more effective ways of monitoring sandeel stocks to utilize them more rationally for sustainable resources such as continued acoustic monitoring of the resource and comparison with other scientific method to explain the population dynamics of fish in the field. Future work is needed to get more reliable information about Japanese sandeel abundance and distribution in the northern coast of Hokkaido and its surrounding areas with the considerations of other factors such as abiotic and biotic factors in the study. The survey area should be extended to be a representative area of the northern coast of Hokkaido. Also the study could have be routine surveys during summer periods. This is because such information is required to understand the sandeel migration patterns in this area and the effect of fisheries on sandeel stock fluctuation after the fishing season.